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The Feasibility of Manned Orbital Maintenance

31 JANUARY 1962

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MISSILE & SPACE SYSTEMS DIVISION
DOUGLAS AIRCRAFT COMPANY, INC.
SANTA MONICA/CALIFORNIA

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ABSTRACT

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Manned and unmanned space vehicles will have to be repaired while in the orbital environment. This can be accomplished in a limited fashion by machines. However, the most efficient system for performance of maintenance in space will utilize directly the capabilities of the human operator. Machines cannot replace man in versatility and capability when we hold constant such dimensions as volume, weight, and reliability. The latter are important considerations for space systems.

This report is the result of a literature search, with accompanied analysis and evaluation. It is primarily concerned with man in the extraterrestrial environment. It describes many of the prime factors that will influence the use of man in an orbital repair system. Physical, psychological, physiological, and mechanical problems are discussed. Recommendations are presented which are pertinent to the design of system, components, and procedures for the efficient preparation and utilization of the orbital maintenance man.

AUTHOR

Descriptors: Bio-Astronautics, Human Engineering, Weightlessness, Space Flight, Satellite Vehicle Research, Maintainability

PREFACE

This report was prepared by direction of the Project Office, Saturn S-IVB, Douglas Aircraft Company, Inc., Santa Monica, California, under National Aeronautics and Space Administration Contract No. NAS 7-1 as part of the preliminary study and design of an unmanned, orbital rendezvous, space vehicle. By specific request, this report is an overview of problems related to manned orbital maintenance.

The purpose of this report is to assist and guide system, vehicle, and component design engineers in their approach to the design of unmanned space vehicles. Little information is presented on specific design criteria. Additional research, such as recommended in this report, is required before specific criteria can be made available.

Special acknowledgement is made of the assistance of James D. Reske Life Sciences Section, Douglas Aircraft Co., Inc. in the investigation and preparation of this report.

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1. INTRODUCTION

By projecting the state of the art only a few years, we are assured that man can be sent into terrestrial orbit and even into space. Vehicles will shortly be available that will carry one or more men into orbit and return them with "minimum" risk. There is also considerable evidence that man himself, with proper preparation, is ready to withstand the exigencies of space flight.

Manned space flight is expensive. Up until now the only costs have been in money and effort. In the future we must plan to expect losses in human lives. Since the funds available are not limitless, and since there are severe restrictions on the loss of men, many compromises must be made. For example, the functions and capabilities of both men and machines are important alternate considerations for determining the total cost. Man, functioning as an integral part of a space system, is a significant factor in reducing costs and achieving mission success.

Total system reliability is of prime importance in the achievement of space goals. Our experiences show that at the present time equipment reliability is insufficient to expect the majority of unmanned vehicles placed in orbit to function properly when required. Because of the extreme stresses of launch and the severe environmental conditions in space, a relatively large number of malfunctions must be expected in an orbiting vehicle. Furthermore, since time is a factor in determining reliability, the longer a vehicle is in orbit the more unreliable it becomes. The reliability of the unmanned orbiting vehicle becomes increasingly important when related to the "Orbital Rendezvous" concept upon which our space plans are predicated. In order to minimize the risk to astronauts, we must determine and assure, in advance, that all equipment is working adequately when required. A manned vehicle, requiring a rendezvous with a functional orbiting booster stage to accomplish a lunar voyage, will never achieve its mission if the orbiting booster is not functional.

Methods for checking the operability of orbiting hardware are available. These checkout systems can be provided in simple or complex configurations. Generalized or detailed information can be obtained for decisions affecting the launch of rendezvous vehicles from the ground or from orbit. Determination as to the complexity of the checkout system for any vehicle depends on gross system and mission requirements and cost considerations. if an orbiting malfunctioned vehicle can be written off as a total loss, a go-no go checkout system can be used. This is the least costly checkout system and can be light in weight. If the vehicle is to have some type of repair capability, a fault location facility must be included. This will increase the system's complexity and add expensive weight.

The minimum repair concept based on redundant subsystems with automatic or semi-automatic switching devices deserves specific consideration. This concept may impose a maximum weight penalty with a minimum increase in reliability. How much of a real increase in reliability can be obtained by adding complex equipment and switching devices to existing systems? Is the additional cost imposed by the weight of redundant systems justified by an adequate increase in system reliability? What shall be done with those systems (e.g. Main Propulsion System) that cannot be duplicated?

A complete investigation of the problem requires that we determine the feasibility of a full repair capability. This necessarily would include manned maintenance. Also included would be a complex fault location system, a back-up space vehicle system, and a crew of astronauts trained in vehicular maintenance under orbital conditions. System flexibility in adapting to unpredictable demands should be improved by these additions.

Certainly, we cannot afford the waste of expensive space vehicles. Both the no-go and the minimum repair concepts are based on this premise, although one less than the other. The expense and risks involved in manned orbital maintenance are tremendous. Therefore, we cannot have man sent up merely to replace a blown fuse. However, to minimize the possible loss of vehicles, we must utilize manned maintenance. W. B. Askren (1) estimates that manned maintenance and control adds more than 70% to the probability for success of space missions. Furthermore he states "another source estimates that for components to have maintenance-free high reliability for a 30 day space flight would require a mean time to failure of 100 years for the components".

It appears that some compromise between redundancy and manned maintenance is required. The "state of the art" is presently adequate to provide the required checkout and redundant equipment. However, can man, adequately prepared for his environment, perform the required maintenance tasks in orbit? If so, what factors should be considered to best utilize his capabilities?

Unfortunately, man has had little experience in space. Predictions of his utility for orbital maintenance must be based on consideration of the existing data on space environmental conditions. Also to be considered are ground based maintenance factors, and man's capability in and adaptability to earth-bound, unusual, environmental conditions (e.g. submarine). The environmental conditions of space are, of course, the prime problem area.

The OMM (Orbital Maintenance Man) will have problems exactly like those of the astronaut. In fact, for a while he will be an astronaut. However, his work will be further complicated when he dons his space suit, leaves the comfort of a sealed space cabin, and maneuvers around the outside of a malfunctioned vehicle. There he will be closest to the space environment. The OMM must be protected against near vacuum conditions, extremes of temperature, harmful radiation, meteorites, and the effects of weightlessness.

In addition to the environmental factors, the OMM will require special devices to keep him from drifting away from the vehicle; special tools with which to accomplish his tasks; vehicle structure and components designed to his orbital work requirements, and a method of maneuvering both himself and required equipment about the vehicles.

The OMM's problems will be physiological, psychological, physical, and mechanical. His musculatory, cardio-vascular, circulatory, and sensory systems can be seriously affected, particularly by the weightlessness factor. He may suffer from perceptual difficulties and emotional conflicts that will degrade his working ability. The space suit itself will provide psychological problems by separating the OMM from his companions, confining him in a tiny space and restricting his movements.

After looking at the estimated problems facing the OMM, more detailed data on the how's and why's of manned orbital maintenance is required to determine the effect of using this concept in designing future space systems. This is the intent of this study.

2. METHODOLOGY

As discussed above, there is little actual experience in manned space travel. The Russians, who have achieved this, have not extended much information. The only pertinent information available to us presently is documentation of research studies and extrapolations of information from unmanned space flights. This project is based on a literature search, analyses of present space vehicle systems for maintenance and repair, and discussions with knowledgeable professionals. John Glenn's orbital flight had not yet taken place when this study was completed.

The literature search included normal library sources, the Armed Services Technical Information Agency, and documents from various technical societies and related sources. Funds were not available for research on an experimental basis or for obtaining data from research studies currently in progress but not reported in the literature.

The entire project was specifically man-oriented. The majority of the data was collected on the psycho-physical and physiological effects of the extra-terrestrial environment on man. Particular emphasis was placed on the weightlessness factor. Data was also obtained on vehicle structure and component requirements, and the environmental effects on various materials. Of course, available data on the orbital environment was analyzed.

The data consisted of documented references from books, technical papers, and periodicals. Extensive notes were made from the discussions with other professional personnel. System and equipment design engineering data consisted of specification and requirements documents published by the National Aeronautics and Space Administration.

During and after the data was compiled, it was integrated and compared with man's experience in equally hazardous environments. In no area was the data adequate to conclusively establish the possibility of overcoming or circumventing the problem factors.

3. DISCUSSION OF THE DATA

In determining the feasibility of manned orbital maintenance, the prime problem factor for consideration is the effect of the environment on man. Enough has been published on the extra-terrestrial environment so that there is little need for repeating it here. However, the effects of this environment on human ability and performance is the real factor.

Man can be protected from many of the aspects of environment with an adequate space suit. The space suit should give him protection against heat, cold, harmful radiation, meterorites, and vacuum-like conditions. However, the suit cannot protect him against the effects of weightlessness, or perceptual problems due to the quietness or emptiness of Space.

In addition to environmental protection, the space suit must provide sufficient flexibility to permit the use of hands, arms, and legs for lifting, stability, and manipulation of tools and equipment. Pressure suits of today are far from adequate for providing the OMM necessary protection except in a sealed space cabin. To-date, a space suit such as required by the OMM does not exist. There is experimentation going on in this area and a break-through is expected soon. However, the literature offers very little information.

3.1 Physiological Factors

With the development of an adequate space suit we will have conquered the majority of environmental problems. One major problem which cannot be solved with a space suit is the psycho-physiological effects of weightlessness. Considerable experimentation has been accomplished with various simulation techniques and with extremely small periods of weightlessness. Most of the data available indicates that although weightlessness will cause some physiological problems most are not insurmountable.

Graybiel and Clarke (2), after experimenting with several subjects in a water immersion test for zero-G asthenia, concluded that there are wide individual differences in response to the simulated features of weightlessness. That is, people are effected differently and in an unpredictable pattern. Futhermore, after prolonged immersion in water (simulating weightlessness) there was a small decrement in strength potentials and a severe degradation on the adaptability of the circulatory system. They could find no indication of permanent or harmful results.

In a similar water simulated sub-gravity experiment, Graveline and Balke (3) found some very severe deterioration in muscle tone and cardiovascular adaptability. Marked deviations were also displayed in blood and urine samples. No permanent or harmful results were indicated.

Both of these experiments were designed to display the effects of a prolonged weightless condition. The subjects remained virtually motionless during the experiments for periods up to ten days. This was to simulate the astronaut, strapped to his couch during extended space travel. Both experiments indicated that a minimum amount of exercise would reduce the physiological effects of zero-G. The OMM, in the course of his work should achieve sufficient exercise. Furthermore, the OMM's periods of weightlessness should be in terms of hours, instead of days, if he is utilized on an as required basis (see section 4.2).

Apparently there is some concern over the effects of weightlessness on perception. It is considered possible that zero-G conditions would interfere with the performance of digital and pedal extremities, create visual illusions, and cause physical discomfort due to perceptual confushion.

H. Strughold (4) has done some work on the functions of certain sensors in a weightless condition. He indicates that there should be no reason for a degradation of pedal or digital performance due to sub-gravity conditions. To emphasize his argument he states, "In the gravity free state with gravitational stimulation absent, the exteroceptive function of the mechano receptors is eliminated; their proprioceptive function is not. Since the peripheral mechano receptors are predominantly proprioceptive, there is no reason why precision in performance of hands, arms and legs should be disturbed".

The loss of stimulation to certain body sensors may have a serious effect on the total postural perception. Experimentation has shown that we may see up while we feel down. That is, our visual perception and the perception of other sensory functions disagree as to our relative postural position. Additionally, physiologically activated visual cues sometimes indicate motion when other sensors indicate no motion (e.g. Oculo-Agravic Illusion). (5) These effects could seriously degrade the performance of the OMM by preventing proper eye-hand coordination or possibly cause a type of motion sickness.

3.2 Psychological Factors

Several psychological problem factors will have to be faced by the orbital maintenance man. These, to a great extent, will be similar to those faced by the astronaut, but will have the added factor of separation from the protection of a sealed space cabin. Some of these problems are so apparent there is no need to discuss them here. The following problems are unusual enough to warrant discussion.

The breakoff phenomena experienced by high flying jet pilots may present a real problem to the OMM. This phenomena consists mainly of a severe feeling of insecurity and disassociation from the earth. Lt. C. M. McClure, pilot for the Manhigh III balloon experiment describes this as a persistent feeling of insecurity. (6) The OMM will probably experience this phenomena most severely when he separates himself from his spacecraft to accomplish his work.

Personnel to be used for manned orbital maintenance will have to be screened for reaction to confinement. Although the duration of confinement is relatively short, the additional psychological stresses (due to the unusual environment) could result in an intolerable situation for some individuals. Except for communication media (radiophones), the OMM will be virtually alone, confined in a rigid or semi-rigid space suit.

Here on earth we learn to live with noise. Space, as we know it now, is extremely quiet, for there is little air to conduct noise. Except for the intra-space suit noises and his communication system, the OMM will work in dead silence. Lack of normal auditory stimulation may have an effect on performance. The sound of a hammer striking a nail aids us in pounding the nail in straight. The OMM will not have this cue to assist him in his work. The inordinate quiet will also serve as another stress factor working against the total capability of the OMM. We may have to provide him with background noises or music to maintain an auditory reference.

Space will also remove most visual frames of reference from the OMM. On earth there are trees, hills, bushes, plants, roads, etc. to help us gauge distances and relative positions. We have the ground and the sky to give us visual up and down positions. None of these things exist in space. With his normal perceptual channels disrupted by weightlessness, lighting, and the restrictions of the space suit, the lack of visual frames of reference could interfere with the OMM's perception of spatial relationships and the positioning of himself and his equipment. Vision will be of primary importance. Schock (7), in an experiment using simulated sub-gravity conditions, found that with decreased proprioceptive input, perception of the horizontal and vertical is greatly impaired.

3.3 Physical Factors

Man, in a cumbersome space suit, must be able to move about in Space. To accomplish his maintenance tasks he must be able to maneuver himself, tools, and equipment from one point to another. The zero-G condition will allow him to maneuver weighty or massive materials with ease, if he can effectively maneuver himself. Weightlessness is also the greatest problem in his ability to move around. Walking, crawling etc. require gravity to provide sufficient friction for motion. A man running in space would be similar to a man running in 20 feet of water. Neither will get very far.

Several methods of accomplishing mobility in a weightless condition are being considered. Simons (8), concludes after limited experimentation that magnetic shoes hold out a possibility for maneuvering in a sub-gravity condition. He noted that subjects became oriented to a foot down position. The surface to which one foot is anchored, regardless of its location, is considered the down position. Magnetic shoes provide the capability for anchoring the feet and obtaining orientation. Furthermore, with proper adjustment these shoes permit sufficient friction for a person to walk while weightless. The use of magnetism creates problems. Present space vehicle structures do not include large quantities of magnetic type materials. The effect of magnetism could be severe on certain of the sensitive subsystems on the vehicle. Adding a coat of magnetically affected material to the structure for the purpose of personnel mobility, would impose a severe weight penalty.

Simons and Gardner (9), a later study, suggested other personnel maneuvering devices such as gas guns and personnel gyros. Experiments with these devices show possibilities of usefullness. However, they also brought out additional problems related to man's center of gravity and his ability to reorient himself after "tumbling" and other gyrations.

A modification of the gas gun concept has recently been developed by Bell Aero Systems Co. (10). This system includes the use of high pressure gas propellants fired through fixed location, controllable nozzles. Maneuvering is permitted in a zero-G environment by rotating the individually controlled nozzles. This system shows promise; however considerable research must still be accomplished before it can be utilized.

After the OMM achieves mobility for himself and equipment, weightlessness poses additional problems. While turning a screw driver to install a piece of equipment, the OMM could find himself turning around the equipment. Operating a rivet gun could result in the OMM flying off into space. The situation is essentially the same when using any tool which requires a force to keep the tool in contact with the object. Many experiments have been conducted on these particular effects of weightlessness. (11, 12, 13, 14) Results indicate that specially designed anchoring devices and tools will be required for the orbital maintenance man to accomplish his tasks.

The aforementioned problem areas are considered, by the author, to be the major man-oriented factors affecting the viability or performance of an orbital maintenance man. These are also the factors which will probably have the greatest affect on the design of vehicles and equipment for the most efficient utilization of man's capabilities as a space repairman.

4. CONCLUSIONS AND RECOMMENDATIONS

That man is required as part of an orbiting space system has been determined logically and systematically. In searching the literature concerned with space systems, it is difficult indeed to find any opinion opposed to the concept that man is one of the most efficient and economical subsystems for maintenance and repair of space vehicles. The opinion of most experts is concurrent with that stated in an article by D. T. McRuer et al, (15). "Then, with a small stock of space modules and parts, an actual physical system with only one or two redundant channels can approach an effective system with much more redundancy, with the man serving as judge over mechanical inconsistencies. Thus a prime human role in space will be that of failure detection, replacement, and repair."

4.1 Man and the Environment

Can man stand the rigors of the extra-terrestial environment? If so, will his requirements degrade system performance or create excessive expenses? These questions must be answered separately.

On the basis of existing information, man can exist in space and apparently can achieve acceptable performance levels. Experiences of man in other unusual environments indicate that man can survive and perform adequately under extreme conditions. Deep sea diving, skin diving, extended periods of submarine operations, arctic, antarctic and high altitude experimentation are examples of this. Similarly to the above stated conditions, the orbital environment requires man to have special equipment to survive and perform.

There is nothing in existing literature to indicate that an Orbital Maintenance Man cannot survive in space. This is not possible today, of course. Development of an adequate space suit is necessary. The space suit will protect the space man from most of the environmental hazards. It is generally expected that an adequate space suit will be available within three to five years (16).

The psycho-physiological problems created by the extra-terrestrial environment are not all solved by the space suit. The zero-G factor of the environment poses physiological and perceptual problems which are not completely understood at present. Furthermore, there are other psychological and physical problems which also must be overcome.

Most experts agree that the physiological problems are not insurmountable. Present knowledge indicates that effects of weightlessness on the cardiovascular and similar systems should be relatively minor due to the short duration of the OMM's stay in space. The physiological effects on perception however, bring out some major problems. Although the effects of sub-gravity conditions on the somasthetic sensors does not severely affect man's performance, these effects do create visual perception problems. A confusion between the perception of postural attitude sensors and visual perception can also occur and cause problems.

The psychological problems of the orbital space mechanic are many and varied. They range from perceptual problems to well known fears, such as claustrophobia. It is believed that none of these problems are unsolvable.

4.2 Methods and Requirements for Manned Orbital Maintenance

There are two additional methods for overcoming some of the physiological and psychological problem factors described above. These are selection of personnel and adequate training.

By subjecting OMM candidates to the same rigorous selection process that the astronauts go through, the physiological problems can be minimized. The pilot for the Manhigh III experiment was able to maintain more than adequate performance, although enduring severe physiological stress, due to his superb physical condition (6).

In addition to physical condition the selection process can assure that only highly motivated and psychologically stable individuals are chosen. These factors will help to reduce the degradation of performance due to psychological stress.

Proper and sufficient training, where possible, will also prepare the orbital maintenance man for the problems of space work. (17) Experimentation has established that some perceptual problems can be overcome by training. It is known that man can be trained to maintain posture in the absence of tactile stimuli; he can also be trained to disregard sensory conflict and depend upon reliable instruments. (18)

Training, special design engineering, and special devices and tools, will permit the OMM to maneuver about in space and also perform his functions. Devices designed to propel the space mechanic, stabilize him at his job station, and provide him with some degree of perceptual orientation are presently being developed. These devices should be available by the time they will be required.

Extensive development of concepts and designs of tools for manned orbital maintenance is now going on. Particular consideration has been given to the reaction of metals in the extra-terrestrial environment and to the factor of weightlessness and human performance. One noteworthy study is concerned with the modification of existing tools and equipment for orbital use (19).

It now appears, by projecting our engineering, production, and biomedical capabilities just a few years, we can state with some certainty that man is capable of performing maintenance on orbital vehicles. We have determined that he is required as a tool, that we can get him up there, that he will survive and perform while there. A need for discussion of factors that are equipment and cost-oriented instead of man-oriented now appears to be evident.

If man is to be used in orbital maintenance and repair, it will be necessary to have a complete back-up space vehicle system. This system must be capable of placing an Apollo type vehicle with a three man crew into a three hundred mile orbit. This vehicle must incorporate the tools, equipment, and spare components required for repair jobs indicated by the ground based checkout equipment. Three men are necessary to permit use of the "buddy" method to work on the malfunctioned vehicle while leaving one man in the maintenance vehicle. The man in the vehicle will act as a safety back-up to the others while maintaining ground communications.

Sending this maintenance vehicle up will entail considerable expense and risk. It is therefore recommended that malfunctioned vehicles be left in orbit until the accumulated quantity justifies the cost and risk of cost of the malfunctioned vehicles, the types of malfunctions, the availability of the vehicles after repair and the net cost of the repair mission. As recoverable maintenance vehicle costs come down, management trade-off studies will show that ever smaller tasks will justify the trip.

Design of space vehicle structure and subsystems must include consideration for the requirements of the orbital maintenance man. Cable anchoring points, hand holds, and possibly foot holds, must be designed into the structure and skin of the vehicle. This includes the interstage areas. Cable anchoring points are particularly necessary in areas of the vehicle where repairs will be most necessary. These anchoring points will be used to assist the OMM in maintaining the proper orientation and stability to accomplish his work and to anchor tools, replacement components and test equipment.

The philosophy of using man in orbital maintenance seriously affects design concepts for subsystems and components. In designing the subsystems, a decision must be made as to how equipment will be layed out. That is, will the black box concept be used? <u>If not</u>, how can components be designed for optimum maintainability in terms of time-to-repair and environmental conditions of space? <u>If so</u>, how will the quantity, redundancy, size, packaging, and connecting devices for the black-boxes be determined?

The "black box" component, remove and replace concept is recommended for sub-system design. This recommendation is based on many factors including the following:

a. Minimize the duration of the OMM's exposure to space environment.

b. Minimize the skill requirements for the OMM.

c. Minimize the number and type of tools and equipment required for repair.

d. Minimize the effect of the anthropometrical factors related to space-suited man.

e. Optimize human capabilities in an extra-terrestrial environment.

Determinations as to the factors of size, quantity, packaging, etc. for component design should be based on system and mission requirements, reliability of various equipments, and the requirements of the Orbital Maintenance Man. This will permit specification of those components which are so reliable that they need not be duplicated; those that are less reliable,but capable of being duplicated; those that can be repaired by replacement and those that require repair on the vehicle.

In addition to developing the basic component design, connecting devices, tools, and related equipments must be designed with reference to the structure, component, and orbital maintainability design requirements. In designing to man's requirements some of the factors to be considered are:

a. Lack of adequate visual and tactual cues. This may require designing self-aligning devices.

b. Lack of stability due to weightlessness. This necessitates design of tools and equipments that do not require special torque or force requirements in order to be used by man.

c. Minimum repair time available. Component and other connections should be of the quick disconnect type. Equipment locations should be centralized to minimize personnel logistics.

This study was intended only to determine the feasibility of using man in an orbital or space vehicle repair system. On the basis of the existing information available to the author it has been determined that manned orbital maintenance is feasible. Physiologically, psychologically, physically, mechanically and environmentally, it appears that an adequately protected man can perform sufficiently to be used as an integrated part of an orbital repair system. The study has been mainly man-oriented. Not all factors have been covered. However, there is sufficient evidence to indicate that the concept of manned orbital maintenance is quite tenable.

4.3 Other Approaches to Manned Orbital Maintenance

The entire concept, as it appears here, is based on the development of an anthropomorphic space suit which will allow man to leave a sealed space cabin to accomplish his maintenance tasks. Some sources indicate a possibility that this will not be achieved. However, with some slight modifications in the recommendations concerning related tools and equipment, the orbital maintenance man may be able to remain in a sealed space cabin and perform his duties remote control (20). Remote control of course brings in its own special problems and there is no need for a discussion of these now.

Another method of manned orbital maintenance is presented by the satellite dry-dock approach such material as using an enveloping plastic bag. This method permits the entire vehicle to be brought within the controlled environment of a space station for maintenance. However, the space-station will not be available to meet early orbital maintenance requirements. Since this method will include all of the prime problems presented in this report except for the space suit, little change is necessary in the recommendations prescribed.

Without a doubt, a great deal of additional research on all the problem factors described is necessary. Actual human experience in space is a prime requirement. An adequate space suit must be developed and a host of design details and procedures must be created and tested. However, we know that man is one of the most capable, versatile, easily available systems yet devised, and we must utilize his capabilities to the fullest in extending our total abilities and achievements in Space.

5. SUGGESTIONS FOR ADDITIONAL RESEARCH

The prime requirement is for research that must be accomplished in space. The space environment cannot be duplicated on earth. Specific methods and procedures to deal with the problems of space will only be developed after experience with extra-terrestrial environment.

Among the problems that can be studied in an earth or simulated space environment is one concerned with the effect of radiation on materials in vehicle structure and components with relation to secondary radiation. Although there is not presently too much concern over secondary radiation, the idea of an orbital maintenance man having to handle material which has become radioactive after an extended period in orbit is not comforting.

Sub-gravity conditions have been simulated by water immersion. Anthropometric data on space-suited man doing actual maintenance tasks can be obtained by use of the immersion method. Human engineering criteria are needed today for design of tomorrow's space vehicles. Water immersion with proper techniques can provide valuable data on the performance of man with tools, equipment. Data can also be obtained on the optimum size of components and types of connectors for effectively using man's capabilities in a weightless environment.

Additional research must be accomplished on the selection of personnel for manned orbital maintenance, physiological as well as psychological. The specification for the space mechanic most assuredly goes beyond that required for the orbital astronaut.

Estimating the reliability of equipment is another area where the need is great. Determinations of design requirements for in-space maintainability will depend to a great extent on the accuracy of equipment reliability estimates.

Development of new training techniques based on the space environment is necessary to optimize the capabilities of the maintenance man in space. To limit personal risk, no one individual will make very many trips to accomplish orbital maintenance. Furthermore, his time of exposure in the extra-terrestrial environment must be of limited duration. He must know what to do, and how to do it best, when he gets there. Ground based training in simulated conditions must be developed to minimize time requirements in space.

There are many other areas where additional research is required. The author does not pretend that they have all been covered in this report. Furthermore there are many problems yet undiscovered. Nevertheless, man will get into space, and he will be part of the system that gets him there. "Human intelligence and manual skill in servicing the complex mechanism of space vehicles or repairing breakdowns in flight are not readily dispensed with or replaced." (21)

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